OSSE Observations of Blazars

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ABSTRACT

The Oriented Scintillation Spectrometer Experiment (OSSE) on the *Compton Gamma Ray Observatory* has observed four of the active galactic nuclei detected by EGRET (Fichtel *et al.* 1993) at photon energies above 100 MeV; namely, 3C 273, 3C 279, MRK 421 and PKS 0528+134. These sources show blazar properties at other wavelengths. Only 3C 273 and 3C 279 were detected with high significance in the OSSE energy range, 0.05 - 10 MeV. However, not all of the OSSE observations were contemporaneous with the EGRET detections. The OSSE exposures varied from 10 weeks on 3C 273 (in 8 separate viewing periods) to 3 weeks on PKS 0528+134. When combined with contemporaneous COMPTEL observations of these sources, we find strong evidence for spectral softening between the hard X-ray and medium energy gamma-ray bands in 3 of the 4 sources. Constraints provided by the OSSE observations on models of blazar emissions are discussed.

INTRODUCTION

The EGRET instrument on the *Compton Gamma Ray Observatory* has reported 16 extragalactic sources of radiation above 100 MeV during Phase 1 (Fichtel et al. 1993). These sources have been identified with radio-loud active galactic nuclei which show blazar properties at other wavelengths; these properties include high optical polarization, extreme optical variablility, flat-spectrum radio emission associated with a compact core, and in some cases apparent superluminal motion. Such properties are thought to be produced by those few, rare extragalactic radio galaxies and quasars that are favorably aligned to permit us to look almost directly down a relativistically outflowing jet of matter expelled from a supermassive black hole. Many of the current theoretical interpretations of these results indicate that the gamma rays are associated with jet activity near a supermassive back hole, but the origin of the gamma radiation is presently a subject of considerable theoretical controversy. An accretion disk origin of the gamma rays is also possible. No agreement exists regarding the distance of the gamma-ray emission site from the central engine, the acceleration mechanisms energizing the particles, or the radiation processes which make the gamma rays.

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OSSE has been quite successful in detecting the gamma-ray blazars discovered by EGRET: at present OSSE has seen two (3C 273 and 3C 279) out of the four gamma-ray blazars which were pointing targets, and has obtained a minimal detection of PKS 0528+134 (2.4σ in energy range 0.15 - 0.30 MeV) during two separate viewing periods. Even so, the evidence is mounting that the spectra of gamma-ray blazars with joint (although not necessarily simultaneous) OSSE/EGRET observations display a softening between the hard X-ray and high energy gamma-ray ($\sim$ 100 MeV - 1 GeV) regimes. This is seen most clearly in combined OSSE, COMPTEL, and EGRET spectra for 3C 273 and 3C 279, and is also required by OSSE's weak detection of PKS 0528+134.

OBSERVATIONS

OSSE observations of 3C 273 were carried out during eight separate viewing periods: 1991 June 15 - 28 (viewing period 3); 1991 August 22 - September 5 (viewing period 8); 1991 October 3 - 17 (viewing period 11); 1992 August 12 - 15 (viewing period 36.5); 1992 September 7 - 13 (viewing period 39); 1992 December 22 - 29 (viewing period 204); 1992 December 29 - 1993 January 5 (viewing period 205); and 1993 January 5 - 12 (viewing period 206). Contemporaneous data with COMPTEL (Lichti et al. 1993) and EGRET (von Montigny et al. 1993) were provided only for viewing period 3, however. In this viewing period, each of the four OSSE detectors independently accumulated source and background spectra, chopping every 2 minutes. The total on-source observing time (per detector) during viewing period 3 was 2.2 x 10^5 seconds. During this viewing period, 3C 273 was observed at a count-flux of 14.6 ± 0.4 x $10^{-3} \gamma cm^{-2} s^{-1} MeV^{-1}$ in the energy range of 0.05 - 0.15 MeV.

3C 279 was observed during five separate viewing periods: 1991 September 19 - October 3 (viewing period 10); 1992 September 7 - 13 (viewing period 39); 1992 December 22 - 29 (viewing period 204); 1992 December 29 - 1993 January 5 (viewing period 205); and 1993 January 5 - 12 (viewing period 206). The EGRET instrument observed 3C 279 during 1991 October 3 -17 (viewing period 11) (Kniffen et al. 1993), and data from COMPTEL during this time frame has not been published; therefore, only viewing period 10 was used in this analysis. Only two detectors were pointed at 3C 279 during OSSE viewing period 10, with a total on-source observing time (per detector) of 1.7 x 10^5 seconds. The count-flux at 0.05 - 0.15 MeV was 6.7 ± 0.7 x $10^{-3} \gamma cm^{-2} s^{-1} MeV^{-1}$.

MRK 421 was observed during three separate viewing periods: 1991 July 12 - 26 (viewing period 5); 1991 July 26 - August 8 (viewing period 6); and 1991 September 12 - 19 (viewing period 9.5). The instrument configuration during these observations included various combinations of detector coverage, as well as differing gain adjustments and offset pointing angles. The total on-source observation time ranged from 1.4 x 10^5 seconds to 2.6 x 10^4 seconds, per detector. OSSE was only able to provide upper limits for MRK 421 during each viewing period, at a count rate of < 1.0 x $10^{-3} \gamma cm^{-2} s^{-1} MeV^{-1}$ at 0.05 - 0.15 MeV. Non-contemporaneous data from EGRET for MRK 421 (Lin et al. 1993) was obtained during the observation 1991 June 27 - July 12 (viewing period 4).

OSSE observed PKS 0528+134 during two viewing periods: 1992 October 8 - 15 (viewing period 41); and 1992 November 3 - 17 (viewing period 44). Only two detectors were pointed at PKS 0528+134, and the total on-source observation time (per detector) was 3.6 x 10^4 seconds for viewing period 41 and 6.9 x 10^4 seconds for viewing period 44. Only a minimal detection was possible for this source during each viewing period at a count rate of 1.06 ± 0.44 x $10^{-3} \gamma cm^{-2} s^{-1} MeV^{-1}$ at 0.15 - 0.3 MeV. Non-contemporaneous data from EGRET (Hunter et al. 1993) was obtained during the observation 1991 May 6 - 30 (viewing period 1), and from COMPTEL (Lichti, private communication) during 1991 April 22 - May 7 (viewing period 0) and 1991 May 6 - 30 (viewing period 1).

ANALYSIS AND RESULTS

Time-averaged count spectra for all sources were obtained by subtracting an estimated background spectrum from each 2-minute source spectrum, then summing the resulting background-subtracted spectra, detector-by-detector. The background for each 2-minute source spectrum was estimated from a quadratic fit to the three (or four) temporally nearest offset-pointed observations (Johnson et al. 1993). The resulting summed spectra were then fitted using forward-folding with nonlinear least-squares fitting techniques. Forward-folding consists of folding an input photon spectrum through the instrument response and comparing resultant count spectrum with the observed spectrum. The photon model parameters are then modified to minimize the χ^2 for the fit.

Spectra of each blazar source were fitted using either a power-law model or a power-law with break model. Figure 1 reproduces the best-fit model spectrum for each individual source, corresponding to the spectra detailed in Table 1. Note the specific viewing periods analyzed for each source in the figure caption. The errors given in this table are the 68% confidence limits for joint variation of the respective parameters of interest.

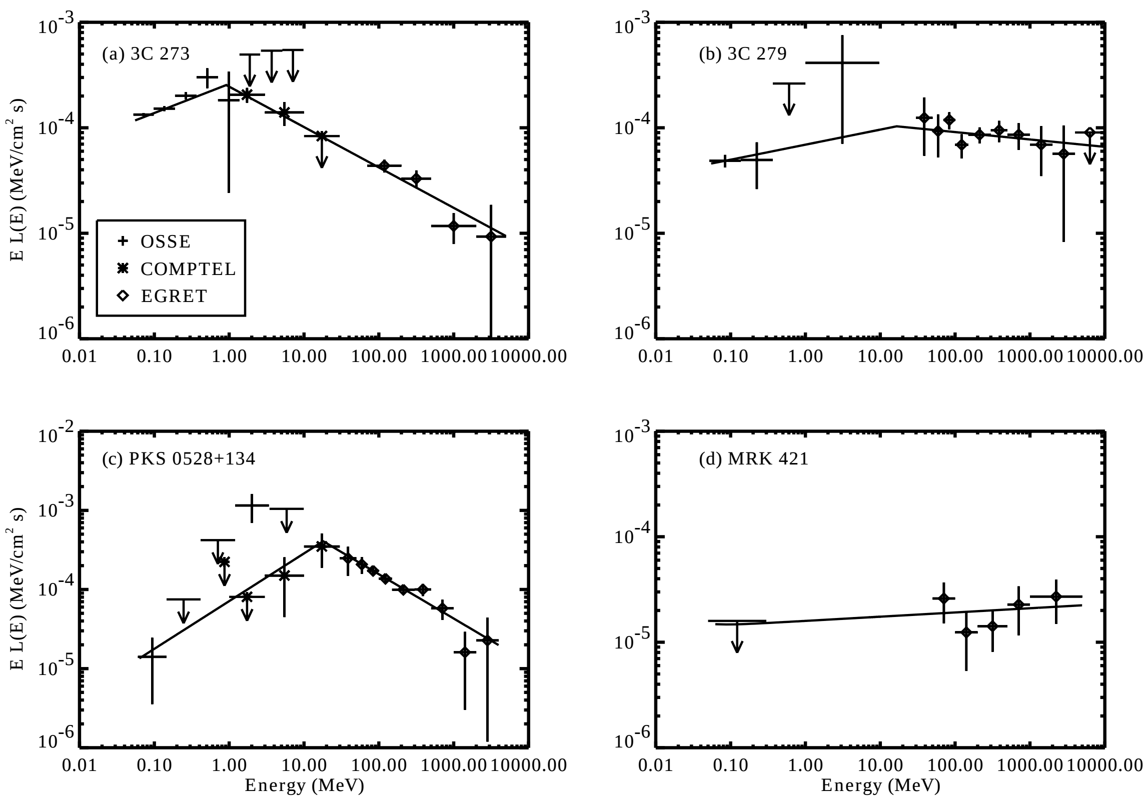

Figure 1: *Spectral Data of (a) 3C 273 (vp 3), (b) 3C 279 (OSSE data during viewing period 10; EGRET data during viewing period 11), (c) PKS 0528+134 (summed OSSE viewing periods 41 and 44; summed COMPTEL viewing periods 0 and 1; EGRET data from viewing period 1), and (d) MRK 421 (summed OSSE viewing periods 5, 6, and 9.5; EGRET viewing period 4).*

Results for 3C 273 clearly show the spectrum breaking around 1 MeV with an index change of 0.66. The best-fit spectrum of 3C 279 for a power-law with break model did

Table 1: Spectral Fit Summary

Source	E_{Break} (MeV)	α_1^a	α_2^a	$\Delta\alpha$	$\chi^2/_{dof}$
3C 273	$0.91^{+1.43}_{-0.39}$	$-1.72^{+0.11}_{-0.13}$	$-2.38^{+0.07}_{-0.07}$	$0.66^{+0.13}_{-0.15}$	1.03
3C 279	16.6	−1.86	−2.07	0.21	1.03
PKS 0528+134	18.0^b	$-1.40^{+0.23}_{-0.11}$	-2.56^b	$1.16^{+0.23}_{-0.11}$	1.03

[a] photon index
[b] fixed parameter

not constrain the parameters very well. In fact, a simple power-law spectrum model was also able to provide an acceptable fit to the data.

Because of the minimal detection of PKS 0528+134 with OSSE, the break energy in the power-law with break model was fixed at various values, and the best-fit estimate is provided in Table 1. The upper photon index, α_2, was also fixed at the reported EGRET value. OSSE was only able to obtain upper limits for MRK 421, and the results are not in conflict with the spectrum from EGRET when EGRET's best-fit power-law spectrum (f(E) = 2.1 ± 0.5 x $10^{-11}(E/1GeV)^{-1.96\pm0.14}\gamma cm^{-2}s^{-1}MeV^{-1}$) is extrapolated back into the OSSE energy range.

DISCUSSION

The standard model for blazar sources involves a black-hole accretion disk with collimated jets that are oriented at nearly right angles to the plane of the disk. It is widely accepted that nonthermal relativistic electrons produce the observed radio emission by spiraling in an entrained magnetic field in the relativistically outflowing plasma jet. With the announcement of Compton Observatory results, several different schools of thought have developed in regard to the origin of the gamma rays, which can be simplistically divided into synchrotron self-Compton models, models involving pion radiation, and models involving jet electrons Compton-scattering photons from external sources. Alternatively, the gamma-rays may be produced via pion production and relativistic Comptonization in the underlying hot accretion disks.

By spanning a range of energy some two orders of magnitude lower than the EGRET energy range, OSSE has attempted to test the predictions of many of these models. Dermer & Schlickeiser (1992) and Sikora, Begelman, & Rees (1993) independently proposed that incomplete Compton cooling of injected nonthermal power-law electrons produce the high energy spectral softening in blazars. Such a model predicts a spectral break with a change in spectral index of no more than 0.5, which seems to be in accord with 3C 273 and 3C 279 observations. The PKS 0528+134 results, however, show a spectra break between the X-ray and 100 MeV gamma-ray regime with an index change of as much as 1.16. Such a result would be in conflict with these two models. A break > 0.5 units could result from additional energy losses in the outflowing plasma (Dermer & Schlickeiser 1993). Spectral breaks > 0.5 are also produced in hot accretion disk models (e.g. Becker & Kafatos 1993) due to incomplete cooling by pion-decay electrons and positrons.

The prediction of photon spectra harder than 1.5 in the low energy gamma-ray regime is made in the various models of Bednarek (1993), Melia & Königl (1989) and Protheroe, Mastichiadis, & Dermer (1992). These models are seriously challenged due to the low energy gamma-ray observations by OSSE, showing these blazar spectra significantly softer than 1.5, as shown in Table 1.

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